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Global Precipitation Measurement - Report 8
White Paper

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Greenbelt, Maryland 20771

July 2002

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Editor's Note

The Global Precipitation Measurement (GPM) effort is a partnership between NASA Headquarters, Code Y, and NASA Goddard Space Flight Center. The initiative has entered the formulation period and, as such, many trade-offs and decisions are yet to be made. In an effort to inform the broad reange of interested parties we have developed this White Paper from thoughts of the individual team members It represents our current expectations on how the mission might be assembled but does not represent the final concept or a baseline. As the team approaches Preliminary Design Review, in the Fall of 2003, a revised Concept Document will be released. We encourage feedback from those that read this document and welcome constructive inputs.

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June 2002

1. Executive Summary

Global Precipitation Measurement (GPM) is being formulated within the context of the Global Water and Energy Cycle (GWEC) with the foremost science objectives focusing on improved climate predictions, improved weather predictions, and improved global water cycle/hydrological predictions through more frequent and more accurate sampling of the Earth's precipitation. Table 1 shows the GPM science objectives, how they are linked to the larger Earth Science Enterprise Mission, and the resulting GPM Science Drivers. GPM is currently scheduled for launch in 2007. The current schedule is shown in Figure 1.

Table 1. GPM Mission Traceability

<table>
<tr><th>Earth Science Enterprise Mission</th><th>GPM Objectives</th><th>GPM Science Drivers</th></tr>
<tr><td rowspan="3">Develop a scientific understanding of the Earth system and its response to natural and human-induced changes to enable improved prediction of climate, weather, and natural hazards for present and future generations.</td><td>Climate Prediction – to improve climate prediction through progress in quantifying space-time variability of precipitation along with improvements in achieving water budget closure, plus focused research on relationships between precipitation and climate variations</td><td rowspan="3">Global Coverage – global rain rates with substantially improved sampling of the daily cycle.
Latency - Deliver near real-time and 3- hour products.
Accuracy Threshold - Bias error 1/2 of TRMM.
Precision Threshold - <25 percent.
Measure 4-D structure of rainfall rates and drop size distribution at 5 km resolution.</td></tr>
<tr><td>Weather Prediction – to improve the accuracy of global and regional numerical weather prediction models through accurate and precise measurements of instantaneous rain rates, made frequently and with global distribution, plus focused research on more advanced techniques in satellite rainfall data assimilation</td></tr>
<tr><td>Flood/Fresh Water Resource Prediction - to improve flood and fresh water resource prediction through frequent sampling and complete Earth coverage of high-resolution precipitation measurements, plus focused research on more innovative designs in hydro-meteorological modeling.</td></tr>
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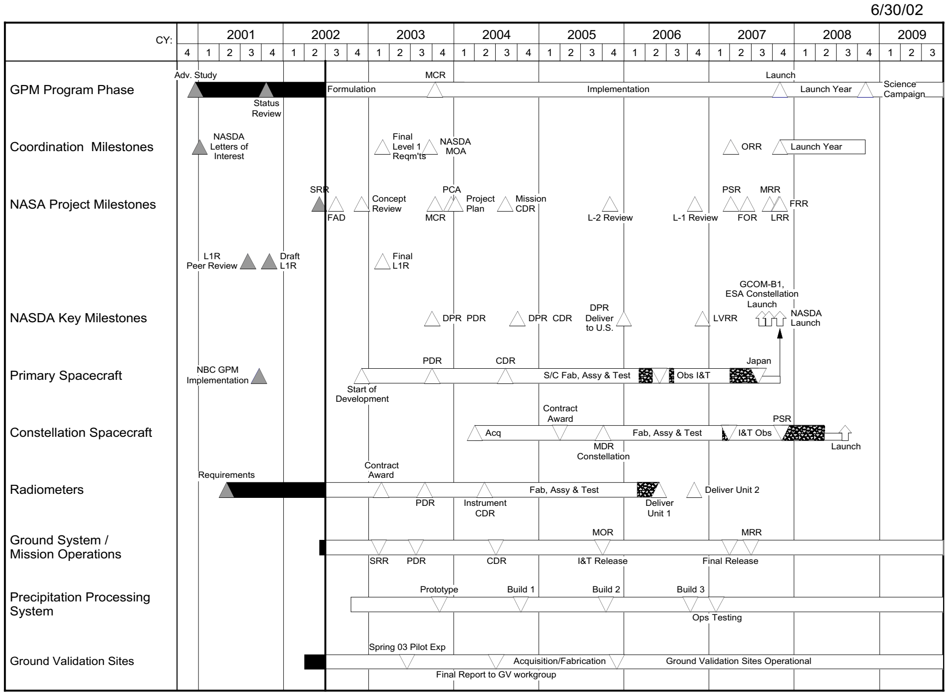

Figure 1. GPM Master Schedule

GPM will acquire global precipitation data sufficient to resolve the diurnal cycle. It does this using a core spacecraft operating in a 65^{o} inclination orbit and a constellation of dedicated and existing spacecraft operating in various orbits, mostly Sun-synchronous, spaced approximately three hours apart. The spacecraft are supported by an array of ground validation and calibration sites that provide ground-based observations of rain and clouds at specific geographic locations. The Mission Architecture is shown in Figure 2.

GPM is an international mission; its success depends on the success of the international partnerships. National Space Development Agency of Japan (NASDA) is the primary partner with the National Aeronautics and Space Administration (NASA). The mission will feature a 3-ton-class core spacecraft, instrumented with a Dual-frequency Precipitation Radar (DPR) and the GPM Microwave Imager (GMI), and a constellation of precipitation-measuring spacecraft contributed by other partners, with a central Precipitation Processing System (PPS) analyzing the data and producing the products, and a set of ground validation sites characterizing the errors in the products. NASA and NASDA will lead the mission and coordinate overall development, operations and research activities. Each partner will participate in their selected areas, which includes hardware (spacecraft, instrument, launch vehicle and launch operations), ground systems development (flight operation system, science data processing, and archive and distribution system), system operations (flight operations, launch operations, and science system operations), data validation, and research activities.

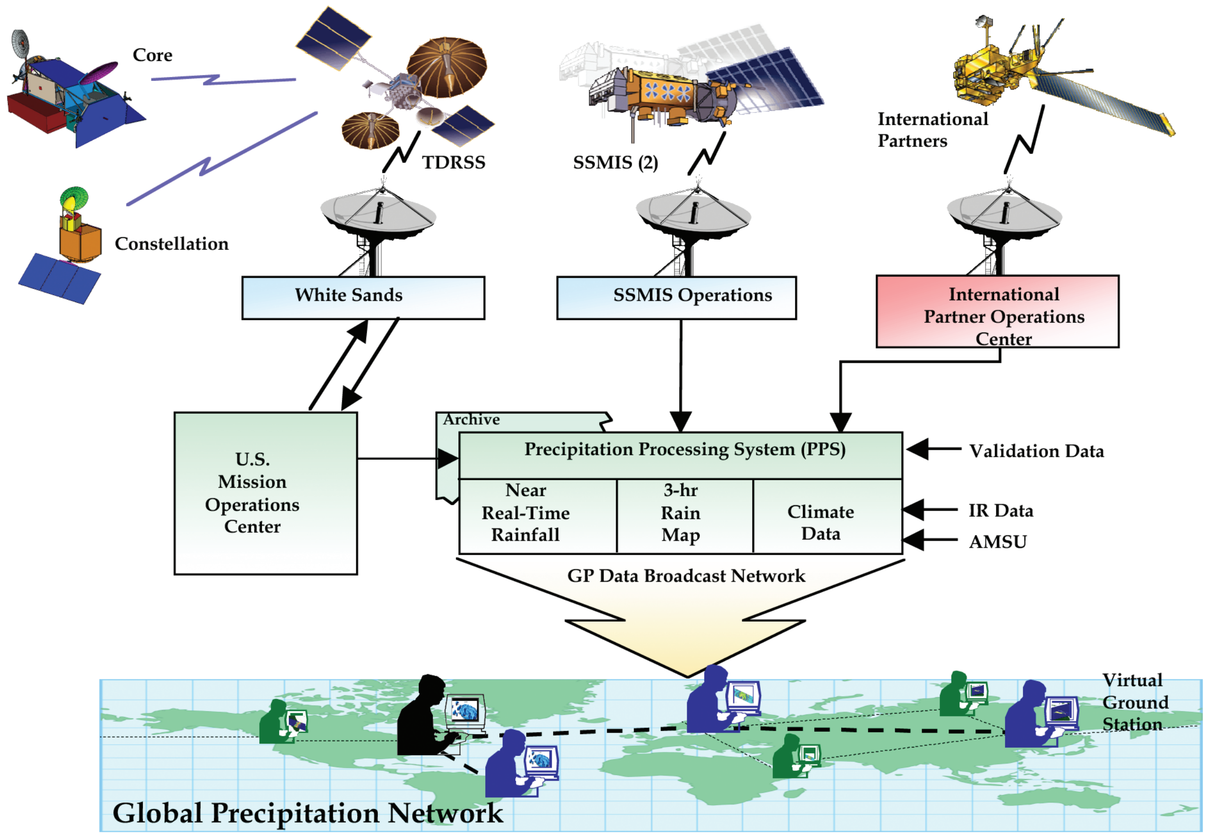

Figure 2. GPM Architecture

NASA plans to contribute, besides the management and leadership, the core spacecraft, a constellation spacecraft, passive microwave radiometers, constellation spacecraft launch, the ground system, and the PPS. NASA will also contribute to and participate in algorithm development and data validation activities.

NASDA plans to contribute a DPR, launch vehicle and launch operation services, and participate in algorithm development and data validation activities. NASDA's GCOM-B1 mission will participate in the GPM constellation.

The GPM core spacecraft is planned for launch in fiscal year 2008 with an operational orbit at 65° inclination and 400 km circular orbit. One NASA constellation spacecraft is also planned for launch in the same timeframe to a Sun-synchronous orbit of 635 km. DMSP satellites will continue to fill two constellation slots. Partners are expected to provide additional constellation spacecraft, but they are not yet explicitly identified. The NASA Ground Validation and Supersites and Regional Rain Gauge Networks will be operational in 2005. Partners, yet to be identified, will provide the additional Supersites and regional networks shown in the program architecture.

The PPS is a federation of cooperating data centers producing and sharing data from active and passive microwave sensors. The center at the GSFC receives data from all members of the federation and creates four types of GPM data products: an outreach rain map updated in near-real-time; a quick-response 3-hour global product available to agencies and individuals engaged in weather forecasting and modeling; routine swath and gridded products available within 48 hours of receiving all inputs; a climate product with high fidelity rain rates available once the appropriate standard data has produced the required dynamic profile information. All routine swath and gridded products as well as the high fidelity climate product are archived and distributed by the GSFC Distributed Active Archive Center (DAAC).

We are actively developing partnerships with many other countries. This paper focuses on the NASA contributions to GPM.

2.0 System Engineering

<u>GPM Space Segment</u>
GPM's space segment includes the core spacecraft and the constellation. The core spacecraft carries a DPR provided by NASDA and the GMI provided by NASA. This spacecraft (Figure 3) provides microphysics measurements of drop-size distribution and latent heat release in storms, and it provides a calibration reference for microwave radiometer instruments throughout the GPM constellation. The spacecraft flies in a 400 km circular orbit, which is low enough to provide 5 km resolution with the radar. The orbit inclination is 65 degrees, which enables the core spacecraft orbit to cut across the orbits of the constellation spacecraft, sample the latitudes where nearly all precipitation occurs, and sample different times of day. The core spacecraft data is returned essentially continuously over a low-rate Tracking and Data Relay Satellite System (TDRSS)-MA link.

The GPM constellation is a collection of spacecraft providing microwave radiometer data streams. This constellation will greatly improve sampling of the Earth's precipitation. Most of these spacecraft are dedicated to other missions, with GPM partners providing the data streams for use in the GPM science data processing. NASA will contribute one constellation spacecraft dedicated to the overall constellation. This spacecraft will carry the GMI instrument.

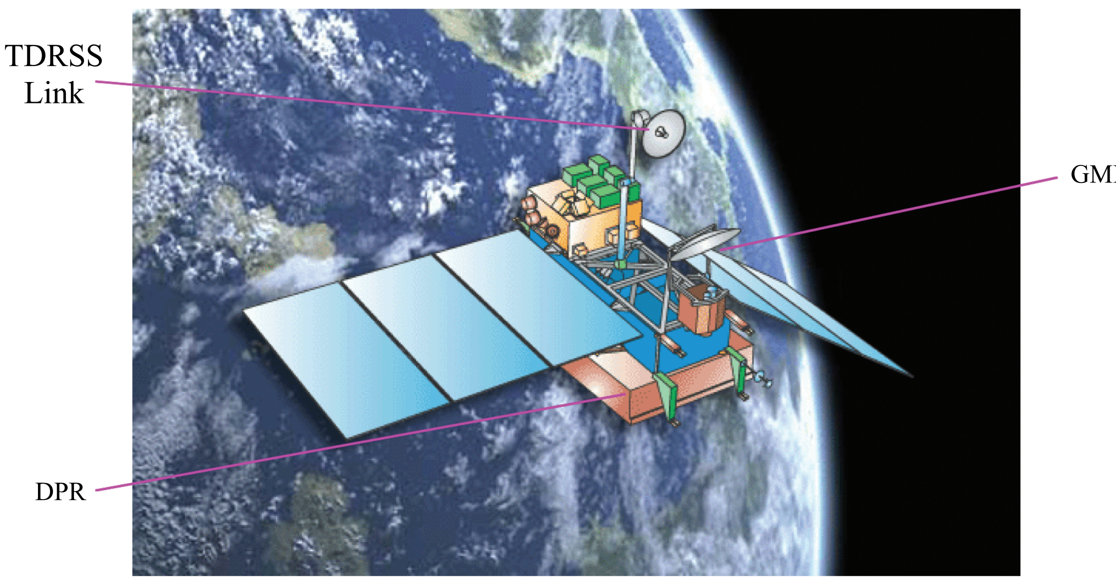

Figure 3. GPM Core Spacecraft Concept

Since most of the constellation satellites are in Sun-synchronous (polar) orbits, the data can be downlinked once per orbit without violating latency constraints, although some outreach users would prefer more frequent access to the rainfall images. Like the core spacecraft, the NASA-provided constellation spacecraft will use TDRSS-MA continuously, reducing data latency to ~2 minutes.

GPM Ground Segment

The Mission Operations Center (MOC), the Ground Validation System, and the PPS comprise the GPM Ground Segment. The MOC operates the NASA GPM spacecraft. All spacecraft commands originate at the MOC, and the MOC monitors spacecraft housekeeping telemetry. The MOC ensures that the spacecraft are operating properly, in the proper orbits, and it verifies that all science data is reaching the PPS.

The Ground Validation System consists of fixed sites, termed Supersites and Regional Rain Gauge Networks. The Supersites contain an array of instruments that provide observations on precipitation, clouds, and atmospheric variables. A processing and analysis facility, associated with the Supersite will, from the local observations and satellite overpass data, provide to the PPS a means of characterizing the systematic and random error of the satellite retrieved products. The Regional Rain Gauge Networks are arrays of rain gauges, typically covering scales over 250 km, and are useful for analyzing the spatial and temporal structure of precipitation.

The PPS ingests data from the space segment, the ground validation facilities, and ancillary data sources to produce science data products. This system will be flexible and scalable to assure the accommodation of additional partners and data streams as they become available.

Constellation Orbit Considerations

The GPM constellation is not an orthodox constellation like GPS or Iridium, where all spacecraft are controlled by a single organization and maintain a fixed relationship. This constellation is actually a collection of spacecraft, most with missions independent of GPM. Many of the spacecraft are Sun-synchronous, but their altitudes and orbital periods are different. The DMSP spacecraft orbit at 833 km, while GCOM-B1 will orbit at 802 km. The different orbital periods cause the ground tracks to move with respect to each other, oscillating between overlapping coverage and missed coverage.

Some spacecraft are dedicated to GPM, and a big challenge for the designer is the optimization of the orbits for those spacecraft, given the varying coverage of the existing spacecraft. Even finding a figure of merit for optimization is difficult. The objective of the GPM constellation is the reduction of precipitation estimate errors by more frequent sampling. A simple measure of average revisit time disguises the difference between sampling uniformly across a day and sampling twice as often over only half a day. Worst-case revisit time emphasizes the gaps in coverage, but since many locations will eventually have one large gap this metric doesn't tell us much about coverage over longer periods. As an improvement over these shortcomings, GPM has been working with a "binning statistics" figure of merit, where the day is divided into 8 three-hour bins for each of thousands of equal-area pixels across the globe, and we count how many of those bins any spacecraft sees at least once.

Figure 4 shows the increasing coverage provided by additional spacecraft within the GPM constellation. The core spacecraft samples only 12 percent of the globe's 3-hour bins, but adding two DMSP spacecraft, GCOM-B1, and the NASA constellation spacecraft bring the total coverage to 70 percent. The green curve on the chart shows the average revisit time vs. number of spacecraft in the constellation. The average time between samples for any given point for the core spacecraft alone is over 24 hours, but adding the 4r other spacecraft brings the average time down to 3 hours. Note that these results are averaged over time and space, masking the fact that some regions have better sampling and some regions have worse on any given day. Also additional spacecraft can have a much bigger impact on some regions than on the global average. Some of this effect can be seen with the addition of a low-inclination spacecraft such as the eighth satellite in the plot. The percent of bins over +/-30º shows a much more dramatic change than the global plot (+/-90º).

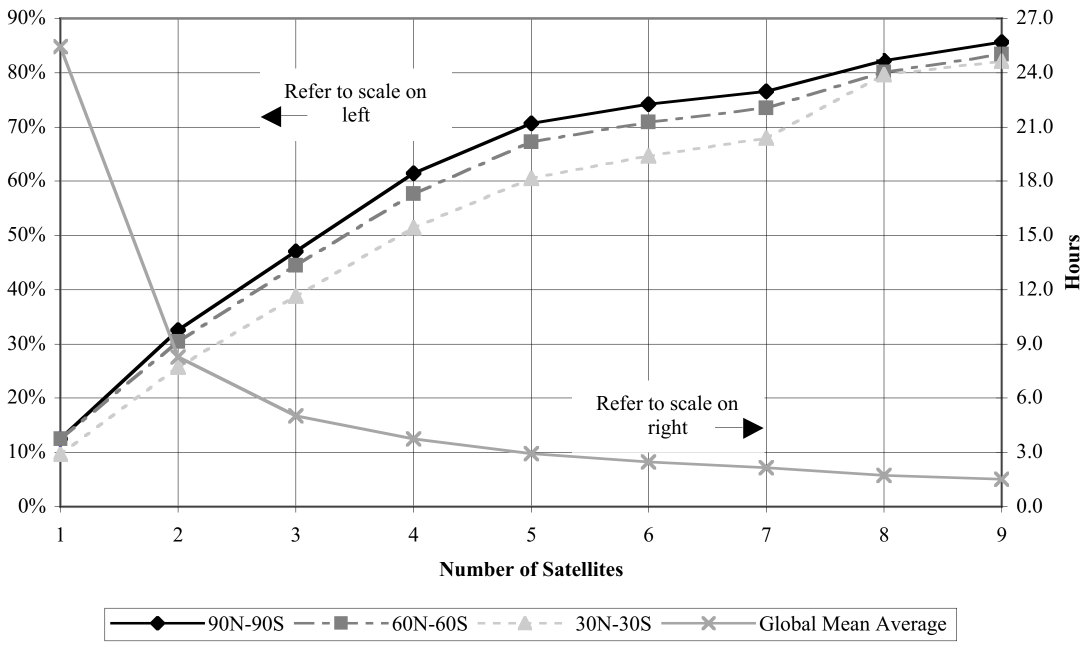

Figure 4. Percent of 3-hr bins Sampled and Global Mean Revisit Time vs. Number of Satellites in the Constellation

3.0 Instruments

The objectives of GPM require that two types of measurements be made: near-global measurements of rainfall, and three-dimensional measurements of cloud structure and precipitation (including drop-size distributions). These measurements can best be performed using two different types of instruments; a passive microwave radiometer, the GMI, and an active radar, the DPR.

GMI Key Parameters

Heritage:	SSM/I, TMI, SSMIS
Mass:	70 kg
Power:	81 w
Acquisition:	Competitive Procurement from Industry
# of Instruments:	2
Spacecraft:	Core, Constellation
Lifetime:	3-Year Minimum
Data Rate:	14 kbps
Antenna Size:	~1.0 m Diameter
Channel Set:	10.65 GHz, H & V Pol
	18.7 GHz, H & V Pol
	21.3 GHz, V Pol
	37.0 GHz, H & V Pol
	89.0 GHz, H & V Pol

The GMI is a conical-scan, passive microwave radiometer that will be used for rainfall measurement. NASA will procure two nearly identical GMI instruments from industry, one instrument to be placed on the core spacecraft, and the other on the NASA-provided constellation spacecraft. Although the vendor for GMI has not been selected at this time, the instrument's design will most likely incorporate substantial heritage from a previous design (i.e., SSM/I-TMI, SSMIS, or CMIS) (refer to Figure 5). This heritage will benefit GPM by reducing the technical risk, time required for design and fabrication, and procurement cost. GMI will be designed to make simultaneous measurements in several microwave frequencies (e.g., 10.7, 19.3, 21, 37, 89 GHz), giving the instrument the capability to measure a variety of rainfall rates and related environmental parameters.
Additional, higher frequency measurement channels (150-165 and 183 GHz) are under consideration in order to provide increased sensitivity for the measurement of light rains frequently found at the Earth's higher latitudes; a decision concerning the inclusion of these additional measurement channels will be made as part of the procurement process.

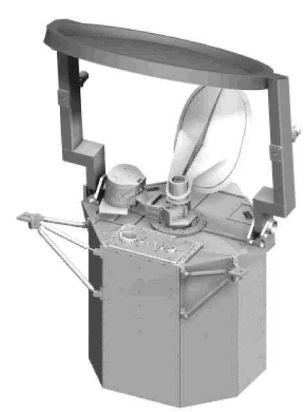

Figure 5. GMI-Type Instrument

The notional design for GMI includes an offset parabolic reflector of approximately 1.0 meters in diameter, which rotates about the instrument's vertical axis. The antenna will point at an off-nadir angle of ~49º, providing a ground measurement swath of ~850 km from side-to-side centered along the ground-track of the core spacecraft. The speed of rotation has not been firmly established, but most heritage systems have used a rotational rate of about 32 rpm. During each 2-second revolution measurements will be made over ~130º scan sector centered on the spacecraft velocity vector. The remaining 230º of the antenna rotation will be used to perform a hot and a cold calibration and other housekeeping functions. The instrument will thus be calibrated once per scan at both ends of its measurement range, or about every two seconds. The rotating mass of the instrument generates momentum which must be compensated either by the instrument or by the spacecraft. Momentum compensation can be incorporated into the instrument, accomplished by a separate wheel placed on the spacecraft, or assumed by the spacecraft attitude control system; a decision concerning which approach will be used has not been identified at this time. The GMI is expected to have mass of about 70 kg. The electronics enclosure should be on the order of 0.5x0.5x0.5 m, supporting a reflector of ~1.0 m in diameter.

DPR Key Parameters
(2 Components: PR-U and PR-A)

Heritage:	Precipitation Radar (PR)
Mass:	660 kg
Power:	570 w
Acquisition:	NASDA Contribution to GPM
Lifetime:	5-Year
Data Rate:	190 kbps
PR-U (13.6 GHz)	
Antenna Size:	2.4 x 2.4 x 0.5 m
Peak Power:	1000 w
Frequencies:	13.6 GHz
Sensitivity:	17 dBZ
PR-A (35.55 GHz)	
Antenna Size:	1.0 x 1.0 x 0.5 m
Peak Power:	180 w
Frequencies:	35.55 GHz
Sensitivity:	11 dBZ

Microwave radiometers are versatile instruments, and when properly configured, can be used to infer a wide variety of phenomena, such as atmospheric moisture and temperature profiles, soil moisture, and sea surface temperature. Its versatility has made it an instrument of choice for a variety of measurement programs, including environmental remote sensing and weather forecasting. Microwave radiometers are planned to be used during the GPM era on several satellites supporting these programs. GPM has initiated the planning and coordination needed so that the measurements made by the instruments will be available to assist GPM in meeting its objectives for frequent, global measurements of rainfall.

The detailed measurements of cloud structure and precipitation characteristics will be made with the DPR. This instrument will be provided to GPM by NASDA (
Figure 6). The DPR is comprised of two, essentially independent radars. One radar operates in the Ku-Band (13.6 GHz) and is referred to as the Precipitation Radar (PR)-U. The other radar operates in the Ka-Band (35.55 GHz) and is referred to as the PR-A. By measuring the reflectivities of rain at two different radar frequencies, it is possible to infer information regarding rainrate, cloud type and its three-dimensional structure, rainrate,and drop-size distribution. The design approach for both radars is based upon the

TRMM PR design, updated as necessary to incorporate new technologies, and modified for operation at the specified frequencies. Like the PR each of the DPR radars uses a 128-element active phased array. The two radars are designed to provide temporally matching ground footprints with the same spatial size and scan pattern. Careful physical alignment of the radar antennas will be required on the spacecraft to ensure co-alignment of the beams is achieved on-orbit. The DPR will have a 245 km wide ground swath, comprised of 49 footprints, each 5km in width. The DPR's mass is estimated to be 660 kg. The antenna for the PR-U will be 2.4x2.4x0.5 m in size, and the PR-A 1.0x1.0x0.5 m.

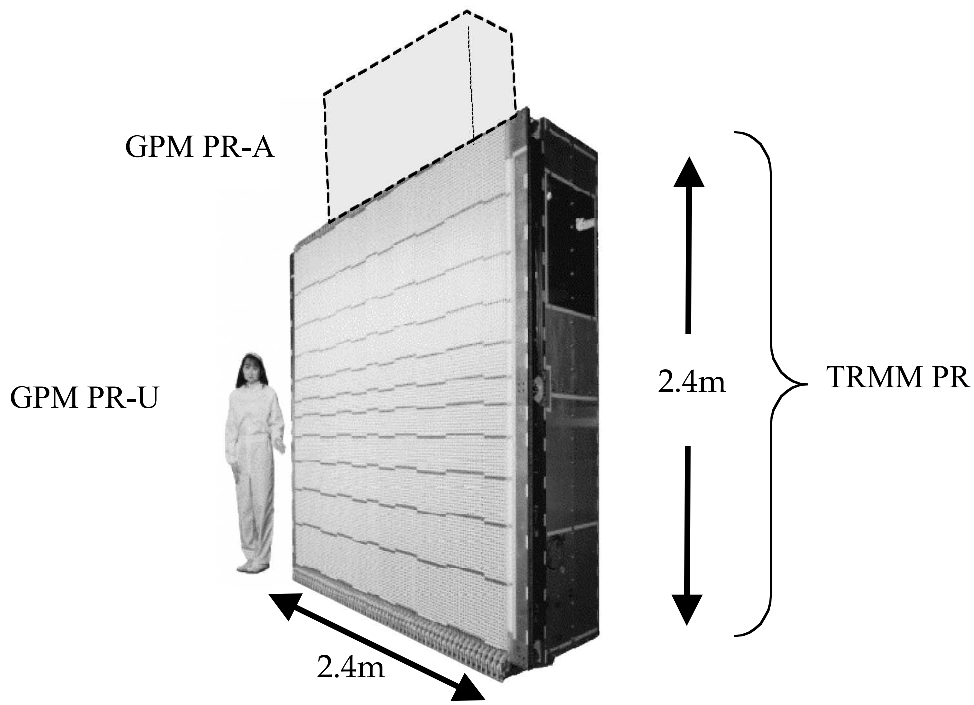

Figure 6. GPM DPR Similar to TRMM PR, but with Added GPM PR-A

4.0 Core Spacecraft and Launch

Key Parameters

Heritage:	MAP, TRMM, and Triana
Mass:	~3200 kg
Power:	1450 w
Acquisition:	TBD
Launch Vehicle:	H-IIA
Launch site:	Tonygoshima, Japan
Lifetime:	3 Year Required, 5-Year Goal
Orbit:	400 km, 65°
Data Rate:	300 kbps

While GPM utilizes many assets of NASA and its international partners, the cornerstone space asset of the mission is the core spacecraft.

The core spacecraft has many similarities with the TRMM spacecraft, namely science measurement and primary instrument suite. But, while TRMM focused primarily on precipitation in the tropics, the core spacecraft's focus is global. For that reason the operating orbit for the GPM core spacecraft will vary from TRMM in inclination. TRMM's inclination was ~35° but GPM's will be ~65°. This way it will capture over 90 percent of the Earth. Also, the minimum mission lifetime for GPM will be the same as for TRMM, 3 years. However, the GPM orbit will be higher than TRMM so that mission life expectancy can be achieved with less effort from the propulsion system. The lower the altitude the higher the aerodynamic drag and the more often the propulsion system thrusters fire to counter that drag affect and stay in orbit. The TRMM altitude was 350 km while GPM's is 400 km.

The core science instruments, the DPR and the GMI, will be integrated onto the core spacecraft and then the integrated spacecraft, once tested, will be shipped to Japan for launch on a H-IIA rocket. In addition to the GMI and DPR we anticipate providing resources (mass, power, and data rate) for an auxiliary instrument. The exact nature of that instrument is to be determined later.

The spacecraft shall be designed to accommodate ~1000 kg of payload mass, ~900 w of payload power and 230 kbps of payload data rate. An estimate of the resulting spacecraft, fully integrated, is ~3200 kg mass with a power generating system capability of ~3,500 w daylight average, and communications bandwidth to support 300 kbps.

<u>Structure</u>

The current concept has the structure as a node and truss design made of mostly aluminum. We are conducting design trades on using composite materials in order to save mass. Also, in order to eliminate the need for controlled reentry of the spacecraft after successful mission life, a trade is underway on what it would take to make a "disintegratable" spacecraft, one that would completely burn up during reentry. We call this approach "Design for Demise". Such a spacecraft could save considerable propellant mass, simplify the thruster layout design and save on mission operations costs at the end of mission life.

Thermal

The thermal design is a passive system and uses heat pipes to move the heat around to the necessary radiators. One side of the spacecraft will always face cold space. This enables the subsystems and instruments to dump their heat, via radiators, with a fairly constant heat sink. Care must be taken to control the spacecraft attitude throughout orbit precession to keep the Sun off that side of the spacecraft. In fact, the spacecraft will be required to perform a 180 degree yaw maneuver every ~6 weeks to ensure that the Sun does not see that side of the spacecraft.

Power

The power subsystem has several major trades. In order to minimize the atmospheric drag effect of the spacecraft and to reduce risk on deployments, the project is investigating a fixed array configuration (the arrays do not articulate to track the Sun). If this is possible, then the system can eliminate the need for the complicated and costly gimbaled solar array drive mechanism. Also, reducing the drag will enable reducing the propellant mass required to maintain orbit altitude. Another trade is Lithium Ion vs. Nickel Hydrogen (NiH) Batteries. Typical low Earth orbiting spacecraft use NiH batteries because of the number of charge/discharge cycles involved in low Earth orbits but they are quite large and massive. Lithium Ion batteries could provide savings in both those areas, but the number of cycles is currently beyond known capabilities. A technology program has begun, with funding from the Earth Science Technology Office (ESTO), to address this shortfall in lithium ion batteries.

Command and Data Handling (C&DH)

The C&DH system design utilizes the 1553 data bus to transfer data around the spacecraft but will package the data to support the Internet Protocol (IP) which will be utilized for the space-to-ground link. The team is investigating utilizing IP as its method of transferring data around the spacecraft but at this time the flight-qualified technology is not available and our data rate does not require it. IP would enable flexibility in the system and, given IP utilization on the ground, could provide end-to-end system compatibility in data format so we will continue monitoring the technology development effort. The system will be designed to support the instrument data volume of at least 230 kbps.

Propulsion

Current concept for the propulsion system is the simple monopropellant system typically employed in low Earth orbiting systems. However, a trade is under way to determine if a bi-propellant system could be employed to provide a better performing system with higher specific impulse thereby enabling the system and propellant mass to be smaller.

RF

The communications system will be designed with the primary mode of getting the data down via the S-band Multiple Access (MA) service from the TDRSS. The concept is to have a continuous broadcast of science data from the core spacecraft to TDRSS. TDRSS would then forward the data to the White Sands ground station, which will forward the data to the MOC. The MOC delivers the instrument data to the PPS, which distributes it to the various data analysis sites in the U.S. and Japan. It is anticipated that the mission will generate ~2.4 Giga-bytes of data a day. As a backup, in case the link with the MA antenna is lost for whatever reason, the system will also be able to downlink the data via the Single Access antenna on TDRSS.

Ground link is also being considered for back-up mode. This implementation will have impacts on data latency, ground stations operations, and mission complexity.

Attitude Control System (ACS)

The ACS requirement is very similar to those on TRMM and is considered readily achievable with existing technologies. Some differences in implementation from TRMM are that GPM will employ a star tracker and a moderately stable gyro rather than an Earth sensor and a ultra-stable gyro and GPM will include a GPS receiver on board to gather ephemeris information real time (TRMM required daily uploads from the ground of ephemeris data.) Experience from TRMM showed that Earth sensors have transient problems when switching from 3 to 4 quadrant and being this close to the Earth degrades the performance of the system. Also, an ultra-stable gyro is very costly compared to the price of a star tracker.

Launch

The GPM core satellite is baselined to be launched by NASDA from the Tanegashima Space Complex (TnSC) located off the southern tip of mainland Japan on Tanegashima Island, Japan. The H-IIA launch vehicle will be used in a dual payload configuration to place the GPM core satellite and the GCOM-A1 Japanese satellite into their proper orbit. The current launch readiness date for the core satellite segment of GPM is November 2007.

Core Launch Vehicle Key Parameters

Heritage:	H-1 and H-II Launch Vehicles
Capability:	4650 kg to 400 km Circular Orbit, 65º Inclination
Co-Manifest:	GCOM-A1
Site:	Tanegashima Island, Japan

The baseline launch vehicle configuration for the GPM core satellite launch (Figure 7) will be an H-IIA 202. The main body of the H-IIA is approximately 53 meters in height with a diameter of four meters. The H-IIA is a two stage launch vehicle with each stage being powered by a liquid hydrogen and liquid oxygen propellant-burning engine. The H-IIA 202 nomenclature denotes the two stage configuration augmented by two solid rocket boosters. The baseline payload fairing configuration will be a 4/4D-LS fairing. This version of the fairing family is a four-meter fairing clamshell type structure used for dual launch configurations for satellites having a diameter of 3.7/3.64 meters or less. The upper payload position is preferred for GPM since the upper compartment can accommodate a larger payload than the lower payload compartment.

The launch campaign will begin with the arrival of the core satellite at the No. 2 Spacecraft Test and Assembly (STA2) facility located in the TnSC launch complex in

Tanegashima, Japan. Once the satellite has been fully tested and configured for flight, the satellite will be transported in an environmentally controlled container to the Spacecraft Fairing and Assembly (SFA) facility for fueling and encapsulation into the fairing with its companion payload. The fairing assembly with the dual payload will be then transported to the Vehicle Assembly Building (VAB) for mounting to the stacked two-stage H-IIA launch vehicle. This launch configuration will then be transported via the mobile launcher to the Pad Service Tower (PST) for a subsequent launch.

From liftoff and throughout its powered flight, the H-IIA will perform its inertial guidance flight using its onboard electronic equipment. The inertial guidance system senses the H-IIA position and acceleration parameters automatically to enable the H-IIA to self correct the flight path according to its scheduled trajectory. If the H-IIA significantly deviates from its flight path, a destruct command shall be transmitted from a ground station for safety purposes.

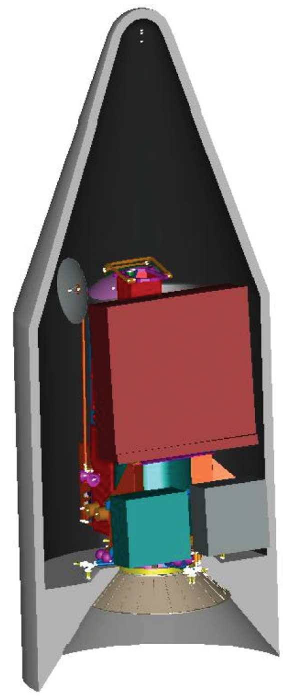

Figure 7. GPM Core in the H-IIA Launch Configuration

Upon achieving the proper orbit, the H-IIA will deploy the GPM satellite with minimal tip off rates with an agreed upon separation velocity. The separation event from the launch vehicle is expected from a NASDA-provided confirmation and/or via spacecraft telemetry utilizing TDRSS. Upon reaching a safe distance from the launch vehicle, the satellite will initiate a deployment sequence for the solar arrays and other deployable mechanisms that are required at that time for the main purpose of acquiring the Sun and establishing communications with the ground. After the outgassing period and in-orbit checkout activities are completed, the GPM will commence its operational mode by taking science measurements and transmitting the data to the ground segment for processing/distribution.

The H-IIA launch vehicle was developed to incorporate lower manufacturing costs and still obtain a high degree of reliability to meet the diversifying launch demands for the Japanese space program. The H-IIA program used the technology development and launch experience gained under the H-II program. The maiden test flight of the augmented H-II family of launch vehicles called the H-IIA occurred on August 29, 2001. The second test flight, which occurred on February 4, 2002, has paved the way for the next flight (DRTS) to occur in the August/September 2002 timeframe. This calendar year will conclude by having one more H-IIA launch (ADEOS II) in November, 2002. NASDA has tentatively manifested an additional 9 or more H-IIA flights in the 2003-2005 timeframe.

5.0 Constellation Spacecraft

NASA will provide one constellation spacecraft that will be a relatively small spacecraft with a single microwave radiometer on board. This radiometer is the same GMI configuration carried by the core spacecraft. The latest conceptual design for the constellation spacecraft is shown in Figure 8. This concept (from GSFC's Integrated Mission Design Center (IMDC)) is designed to utilize half of a Taurus-class launch vehicle, allowing the possibility of an additional GPM spacecraft sharing the launch. The mass and power summary is shown in Table 2. Like the core spacecraft, this spacecraft will utilize TDRSS-MA for continuous downlink, enabling the "virtual broadcast" of data over the Internet.

Key Parameters

Heritage:	Various
Mass:	400 kg
Power:	340 w
Acquisition:	RSDO or Partner
Launch Vehicle:	Taurus class
Launch site:	TBD
Lifetime:	3 Year Required, 5-Year Goal
Orbit:	TBD
Data Rate:	50 kbps

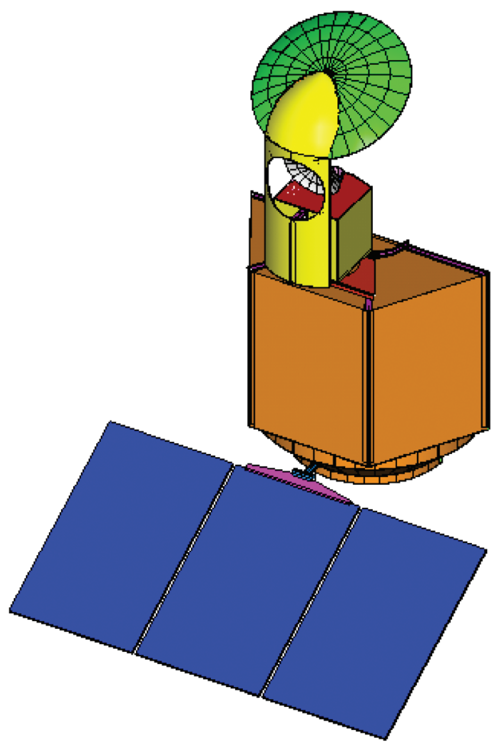

Figure 8. NASA GPM Constellation Spacecraft

Table 2. NASA Constellation Spacecraft Mass and Power Estimate

Spacecraft Bus Subsystems and Structure	Mass (kg)	Power (W)
Bus Structure	45.0	--
ACS	62.7	95
C&DH	24.0	36
Power System	74.7	30
Solar Array Deployment Mechanism	14.0	--
Thermal System	10.0	10
RF Communications	23.0	57
RF Communications Boom & Gimbal	10.0	included
Bus Harness	12.0	5
Separation System, spacecraft side	3.5	--
Propulsion	13.2	25
Propellant	32.0	--
Bus Subsystems Total	**324.1**	**258**
Payload Total	70.0	81
Spacecraft Total	**394.1**	**339**
Spacecraft Total with 20 percent contingency	**472.9**	**407**

A possible dual launch configuration is shown in Figure 9. The orbit for the constellation spacecraft has not yet been selected, but an altitude of about 635 km produces adjacent ground tracks for two spacecraft 48 minutes apart in the same orbit plane. Lower inclinations provide more coverage in regions that need additional coverage and allow greater mass to orbit, but they complicate the spacecraft design. Constellation spacecraft design trades will start in FY03. NASA will use the Launch Services contract (see Table 3) to procure the launch vehicle and launch services for delivery in the fiscal year 2008 timeframe.

Constellation Launch Vehicle Key Parameters

Heritage:	Peacekeeper/Castor 120 Motors and Pegasus
Capability:	785 kg to 635 km Circular, Sun-Sync Orbit
Co-Manifest:	TBD
Possible Sites:	VAFB, CA Kodiak Island, Alaska Alcantara, Brazil

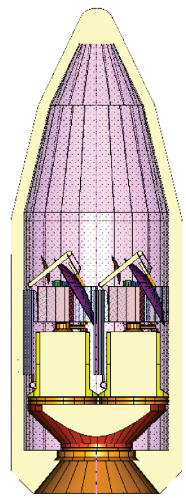

Figure 9. Constellation Dual Launch Configuration

Table 3. Launch Vehicle Performance for Dual Spacecraft Launch

Launch Vehicle	635 km Capability per Spacecraft	400 km Capability per Spacecraft	Fuel Mass to Boost from 400 to 635 km (120 m/s, mono-prop H2N4)
Taurus 2210 (1.6 m fairing)	**355 kg**	**411 kg**	**23 kg**
Taurus 2110 (2.3 m fairing)	**270 kg**	**312 kg**	**18 kg**
Delta 2320-9.5 (2.9 m fairing)	**695 kg**	**764 kg**	**42 kg**

6.0 Mission Operations Center

The mission operations for NASA's GPM spacecraft are routine, automated, and low risk. The instruments are on all of the time, with infrequent interruptions for calibrations. The spacecraft performs most functions autonomously, including orbit determination and station keeping. The spacecraft are in contact with the ground almost all of the time, reducing the operations risk by minimizing the time required to recognize and respond to an anomaly.

TDRSS Key Parameters

Heritage:	Existing System
Acquisition:	Project Service Level Agreement with NASA's CSOC
Core Data Rate:	300 kbps Real-Time 1.4 Mbps Single Access Playback
Constellation Data Rate:	30 kbps Real-Time 180 kbps Single Access Playback

Both spacecraft communicate continuously with the ground through the TDRSS. The communications are interrupted briefly for handovers from one TDRS to another. A standard protocol is used to retransmit any missing data. The MOC provides the PPS with near real time data, 3-hour data sets, and 24-hour data sets (Figure 10).

Backup Ground Stations Key Parameters

Heritage:	Commercial Systems
Acquisition:	Project Service Level Agreement with NASA's CSOC or separate contract
Core Data Rate:	2-4 Mbps
Constellation Data Rate:	1 Mbps

The MOC monitors both primary and the NASA constellation spacecraft and generates the commands for any spacecraft activities. The operations center is only staffed 40 hours per week during normal operations. At other times, automated systems page an on-call operator in the event of a problem. The MOC coordinates the instrument operations with the instrument teams.

MOC Key Parameters

Heritage:	Based on Existing Government Software Systems and COTS Products
Core Acquisition:	Managed In-House; Implemented with Civil Service and Support Service Contractors
Constellation Acquisition:	Currently Planned to be Managed In-House, Combined with the Core MOC. Will be Reevaluated After Constellation Spacecraft Selection.

GPM spacecraft operations are simple. There are very few activities to schedule and the activities do not conflict with one another. The standard protocol allows the data to be delivered autonomously. Orbit maneuvers are performed several times per year – often enough to maintain this expertise but not so often as to be a burden on operations. The two NASA spacecraft do not interact operationally with each other, or with other partner spacecraft.

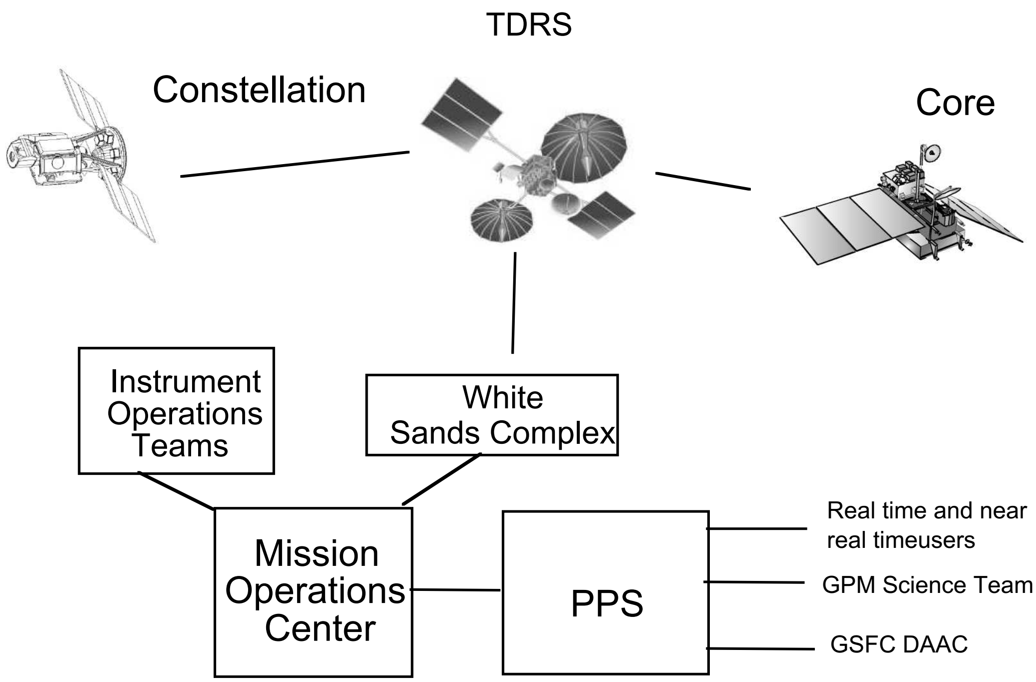

Figure 10. Mission Operations and Ground System Block Diagram

The functional block diagram of the MOC is shown in Figure 11. The MOC operates both NASA spacecraft. The data handling function receives the data from the spacecraft and distributes the housekeeping data for further processing. It also passes raw science data to the PPS. The real time system evaluates the health of the spacecraft and alerts an operator in the event of a problem. The performance evaluation function allows spacecraft engineers to evaluate the spacecraft subsystems over time. The scheduling function schedules command uplink opportunities, generates command loads, and schedules any special activities (such as special calibrations). The flight dynamics function provides predicted orbit data and maneuver plans.

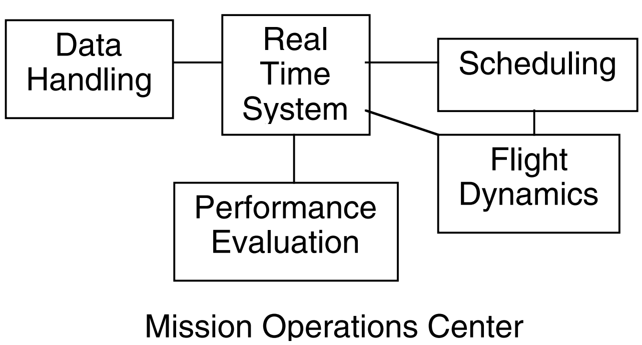

Figure 11. MOC Functional Block Diagram

7.0 Validation

Key Parameters	
Heritage:	TRMM GV Program
Acquisition:	NASA and International Partners
Components:	Focused Measurement Program (FMP) and Routine Product Program (RPP)
Timeframe:	FOP: 2003 to Mission Completion RPS: 2005 to Mission Completion

Ground Validation (GV) is an integral and critical element of GPM with a purpose of providing credibility to the products of GPM so that the relevant Earth science communities can employ GPM products in their work. The products of GV are quantitative estimates of systematic and random error, and of the spatial and temporal structure of error, of the satellite retrievals. By providing quantitative error products to the Earth science communities, the GV program provides increased credibility and utility to the GPM space-borne products.

GPM will build upon the heritage of the TRMM GV program by understanding and implementing well the complex lessons for success. The GPM GV program is composed of two distinct subprograms: (1) a Routine Product Program (RPP) and (2) a Focused Measurement Program (FMP). The following provides a brief description of each program.

Routine Product Program (RPP)

The RPP is a continuous program providing, as products, validation answers on a regular and timely basis to the scientific community through the PPS. The primary elements of the RPP are the Supersite facility, as illustrated in Figure 12, and the Regional Rain Gauge Network. Figure 12 provides a template as to how the Supersites will be instrumented, operated, and interact with the GPM validation customers. The Supersites will become operational two years prior to GPM core launch and will continue operation through mission life. NASA will site, equip, operate, and maintain two of the Supersites and one Regional Rain Gauge Network. One Supersite will be within a tropical oceanic climate while the second will be within a mid-latitude continental regime. Since the two NASA Supersites and the single Rain Gauge Network are insufficient to provide measurements over all climatic regimes and meet the Mission's spatial and temporal requirements, NASA is seeking domestic and international partners to provide additional GV sites. Specifically, NASA is seeking partnerships to provide up to eight additional Supersites and up to five additional Regional Rain Gauge Networks.

The choice of instrumentation for the Supersites is dictated from the required GV products. Figure 12 provides some of the likely candidates for Supersite instrumentation. Most simply, there are two primary products expected from the Supersite operations. These products are in the form or error characteristics and will consist of (1) bias and bias uncertainty factors that are a slow function of space, time, and rainrate, and (2) local-domain space-time error covariance structures. The first product, error bias, will be produced from a dual-frequency radar and radiometer instrument, channel-matched to that of the GPM primary space-borne instruments. The ground-based radar/radiometer is proposed to survey the resolution volume of the space-borne instruments during overpass events. The second product, error structure, will be produced from a multi-parameter (i.e., polarimetric) volume-scanning radar and a network of rain gauges and disdrometers. In these measurements exact calibration of the polarimetric radar and gauge network is not necessary. What is important is the underlying space-time resolution and structure provided by the instruments.

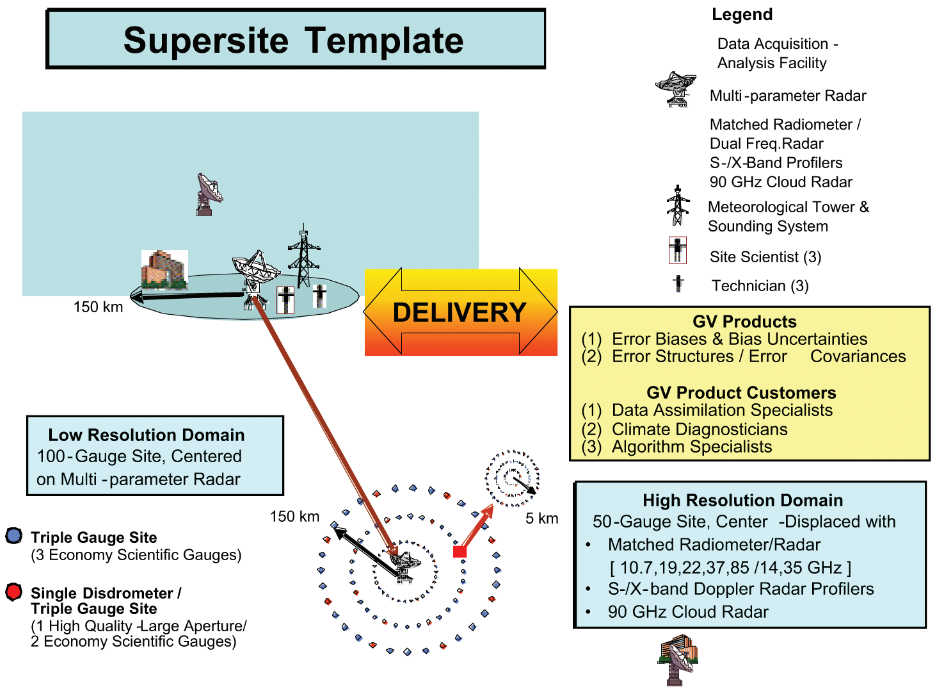

Figure 12. The Ground Validation Supersite is a Key Primary Component to the Routine Product Program

There are three primary customers of the GV Supersite activities: (1) Data Assimilation Specialists, (2) Climate Diagnosticians, and (3) Algorithm Specialists. Data Assimilation Specialists study how to best assimilate satellite-derived precipitation measurements into environmental prediction models including General Circulation Models (GCM), Numerical Weather Prediction (NWP) models, Limited Area Models (LAM), and Hydrological models. The second customer type, Climate Diagnosticians, try to understand the veracity of trends and variations found in their models. The GV Supersite products will be in the form of validation answers, consisting of error characteristics of the retrievals, to these two customers. The third customer, Algorithm Specialists, is interested in improving the accuracy of satellite-derived products through improved algorithms. The Supersite will assist the algorithm specialists through testing and validation of assumptions within the physical models, which form the basis of the algorithms.

Successful implementation of the Supersites depends upon effective and timely communication between the Supersite research scientists and the PPS. Effective communication is particularly important for the algorithm specialists who need reliable and near-real-time alerts of when a Supersite produces a significant deviation in what is observed and what is retrieved with respect to rain rates provided by an overflying satellite. Firstly, the PPS supplies to the Supersite data from the recent satellite overpass. The GV Supersite scientists generate a comparison, with some scientific insight, between their ground observations and algorithms and that of the satellite. These answers are communicated back to the PPS which then communicates to the Algorithm Specialists what the problems are, as they occur, along with the relevant data sets that describe and explain the problem.

Focused Measurement Program (FMP)

The FMP is a diverse mix of research and experiments sharing the common trait of limited and specific goals. Some experimental programs of the FMP will be devoted to climatological and meteorological phenomena. Other experimental programs will posses demonstrational objectives to validate instrumentation suites or data product algorithms. Emphasis of the FMP will be directed to research activities addressing GPM GV risk factors, as the risks are identified. It is expected that GV risk reduction from the focused program will ultimately improve the operational products of the Supersites of the RPP. FMP activities will span a range of complexity from experiments involving a few researchers with ground-based instrumentation to field campaigns involving research aircraft and ships and a diverse complement of researchers and personnel. Regardless of the complexity, the objectives of the FMP experiments will be limited and specific. As contrasted with the RPP, the FMP provides products in a non-routine but deliberate timeframe. Activities of the FMP will commence as early as 2004. Experiments and research will continue in the years prior to GPM core launch and throughout the mission lifetime.

8.0 Precipitation Processing System

Key Parameters	
Heritage:	TRMM/TSDIS
Acquisition:	GSFC Directed, Competed Development and Operations
Products:	Instantaneous Global Precipitation Map, 3-Hour, Climate

The PPS must take into consideration the fact that the GPM is not put into place as a one-time deployment of the complete final array of space and ground elements, but evolves from demonstrations using existing assets and the time-phased addition of dedicated and contributed elements. In addition, the PPS must accommodate variation in assets and data streams as partners join or leave the program over time without requiring major changes in essential equipment or processes.

TRMM and two DMSP satellites currently in orbit carry a set of instruments suitable to demonstrate the data gathering and calibration functions of the core GPM spacecraft and two constellation spacecraft respectively. A demonstration ground validation and calibration site is planned for 2003 to work with TRMM overflights, thereby providing ground validation data. ADEOS II and AQUA data should also be available after their launches in 2002. The TRMM Science Data Processing System is being upgraded to accept the additional spacecraft and ground data. This configuration should be capable of demonstrating each aspect of the PPS - world-wide data gathering, ground calibration, data correlation and multi-asset operations - well before the full-up system is deployed in the 2005 – 2007 timeframe.

The PPS is responsible for the production and distribution of GPM mission data. The process begins with ingest of satellite data from the GPM mission operations center, GPM mission partner data centers, and ancillary data sources. This data is then processed into the various types and levels to produce the standard product set determined and approved by the GPM science team.

The PPS is actually a union of data processing centers at GSFC, the Global Hydrology Climate Center in Huntsville, AL., the NASDA data processing center in Japan, as well as other partner data centers and the DAAC at the GSFC, Greenbelt, MD. Working an integrated data system, these centers produce the products and send them to the DAAC and partner distribution centers.

The PPS produces three distinct kinds of products. On a very timely basis as data comes into the GSFC processing system, a global precipitation map available to all via web access is updated with the latest satellite data. Every three hours, the best instrument data available is combined and quality to create a three-hour global precipitation product with error characterization that can be used in weather modeling and forecast improvement. A key driver in this type of precipitation product is to provide the best quality product as close to the actual data collection time as is feasible. These products are available to designated users within 20 minutes of the collection of the last data bit in the product.

The third type of product is a climate research quality product where the timeliness is less of a driver than the accuracy. These products are produced as the best satellite data stream and ancillary data stream including data from GPM ground validation sites that are available. These climate research quality products are released within 48 hours of having received all necessary data input.

Products are generated through three levels. Level 1 is the calibrated, geo-located, instrument values at the instrument field of view. Level 2 maintains the instrument footprint orientation but converts instrument values to physical parameters, the key parameter for the mission being precipitation rate. Level 3 products aggregate the level 2 physical parameters into different time-space grid orientations. This level provides the key climate research quality products produced by GPM. Figure 13 provides an example of a level 2 product of vertical hurricane (Floyd) structure as well as surface rain-rates derived from the PR on TRMM. An improved version of this instrument will be part of the GPM mission and an analogous product will likely be part of the standard data products.

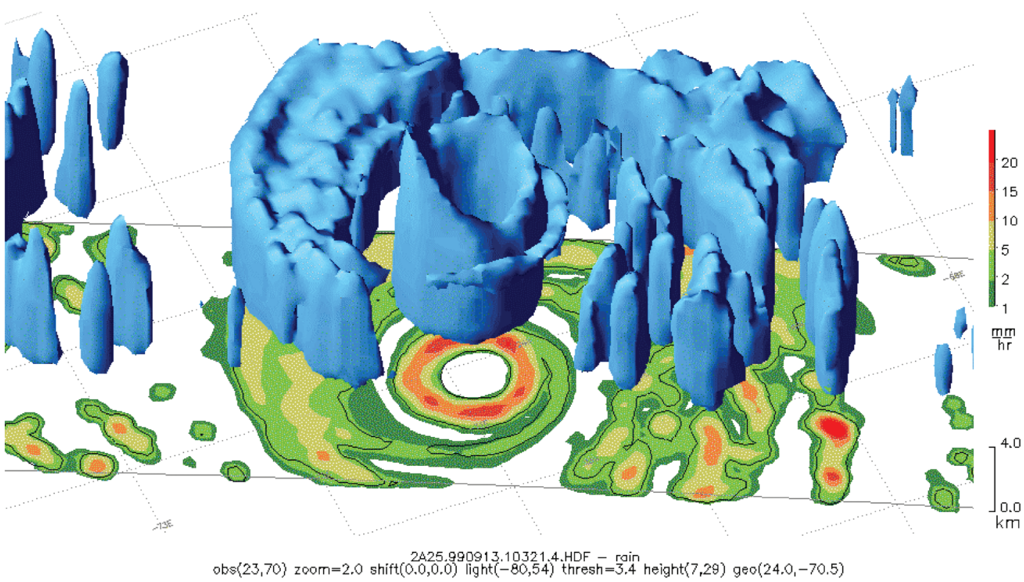

Figure 13. Hurricane Floyd Data Product

All GPM data products are available to users via the GSFC DAAC or regional data distribution centers provided by mission partners (refer to Figure 2).

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Global Precipitation Measurement (GPM) is being formulated within the context of the Global Water and Energy Cycle (GWEC) with the foremost science objecteds focusing on improved climate predictions, improved weather predictions, and improved global water cycle/hydrological predictions through more frequent and more accurate sampling of the Earth's precipitation.

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